Boundary Conditions, Data Assimilation, and Predictability in Coastal Ocean Models

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Award Number: N00014-05-1-0891
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LONG-TERM GOALS

The long-terms goals of this research are to improve our ability to understand and predict environmental conditions in the coastal ocean.

OBJECTIVES

The specific objectives of this research are to determine the impact on coastal ocean circulation models of open ocean boundary conditions from Global Ocean Data Assimilation Experiment (GODAE) Pacific Ocean models, and to address closely related issues of uncertainty and predictability in coastal ocean models.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2009**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Boundary Conditions, Data Assimilation, And Predictability In Coastal Ocean Models**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,College of Oceanic and Atmospheric Sciences,104 COAS Admin Bldg,Corvallis,OR,97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The specific objectives of this research are to determine the impact on coastal ocean circulation models of open ocean boundary conditions from Global Ocean Data Assimilation Experiment (GODAE) Pacific Ocean models, and to address closely related issues of uncertainty and predictability in coastal ocean models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

This research addresses the direct impact on coastal models of boundary conditions from GODAE models. The domain of the nested coastal model is the 'coastal transition zone' (CTZ), which includes the continental shelf and slope, and the adjacent ocean interior. The CTZ is the natural oceanographic regime of interest for coastal modeling applications off Oregon and northern California. It extends offshore about 200 km in this region, and is characterized by energetic wind- and buoyancy-driven flow over the shelf, accompanied by complex, lower-frequency eddy, jet and filament dominated flow over the slope and in the ocean interior, which is unlikely to be properly resolved by basin scale models. Validation of the simulated coastal ocean circulation is provided by existing elements of the Oregon coastal ocean observing system. The closely related issues of uncertainty and predictability in coastal ocean models are being addressed using a variety of empirical and theoretical methods to study disturbance growth mechanisms and to develop uncertainty budgets for these models.

In addition to PIs Samelson, Allen, Egbert, Shulman (who has replaced the recently retired John Kindle), and Snyder, other senior personnel are A. Kurapov and R. Miller, both at College of Oceanic and Atmospheric Sciences, Oregon State University. Dr. Scott Springer has been a full-time research associate pursuing physical circulation modeling. Postdoctoral investigator Dr. Sangil Kim is working on studies of predictability and uncertainty, data assimilation, and assessment of boundary condition effects.

WORK COMPLETED

The work plan primarily involves the implementation, evaluation, and analysis of a nested primitive-equation CTZ-domain models. Since the GODAE Pacific HYCOM model was not yet functioning with full data assimilation capability, it was decided, in consultation with original NRL partner John Kindle, to proceed with nesting the CTZ-domain model in the NRL regional NCOM-CCS (Navy Coastal Ocean Model-California Current System) model. The latter regional model is nested in the Navy's Operational Global NCOM model, which is a component of the Global Ocean GODAE system. Both Global NCOM and NCOM-CCS include assimilation of satellite altimeter and sea-surface temperature measurements. NCOM-CCS has higher horizontal grid resolution than Global NCOM (9 km vs. 12 km) and, in addition, is forced by atmospheric fluxes from a high-resolution COAMPS (Coupled Ocean Atmospheric Mesoscale Prediction System) reanalysis product, which includes the orographically intensified wind stress in the Cape Blanco and Cape Mendocino regions.

Simulations and detailed comparisons with observations have been carried out during for the period 1 May through 1 November 2001, and the results have been described in a manuscript accepted for publication (Springer et al., 2008). This work included analyses of the influence of information supplied at the open boundaries of the nested model, Lagrangian analysis of the source of water parcels found in the offshore, separated, upwelling jet, and the differentiation between deterministic response to wind forcing over the shelf and more unstable, less predictable jet separation and eddy formation processes farther offshore.

A continuation of this study that focuses, in complementary manner, on the downwelling season of winter 2002-2003 has been nearly completed, and a manuscript describing the results is in preparation (Springer et al., in preparation).

To address the predictability of wind-driven flow over the shelf, ensembles of simulations of wind-forced coastal ocean circulation in a periodic alongshore-channel CTZ domain have been analyzed, and the results have been described in a manuscript under review (Kim et al., 2008).

Recent work using the ensemble approach has been directed toward quantitative analysis of the relative effects of boundary data at the northern, western, and southern open boundaries of the nested domain, in preparation for the implementation of data assimilation in the nested model.

RESULTS

For the May through November 2001 OCTZ simulations, the nested model was found to provide a useful representation of flows both over the shelf and farther offshore. The simulation of coastal sea level and shelf currents over the complex topography of the central Oregon coast was quantitatively improved relative to previous regional models, and the representation of coastal jet separation and eddy formation offshore of Cape Blanco was qualitatively improved. Three-dimensional Lagrangian analysis of water parcel displacement indicated that the surface waters inshore of the separated jet were upwelled from near the bottom along the shelf as far north as 45.5º N, and that a large eddy incorporating some of this upwelled water formed offshore in the late summer and carried it farther westward (Figure 1). On the basis of a small ensemble of simulations, initialized on different days, a distinction was indicated between the strongly deterministic response to wind forcing over the shelf, and more unstable, less predictable jet separation and offshore eddy formation processes in the region near Cape Blanco. More details on these simulations and results are provided by Springer et al. (2008).

In the predictability studies, which used ensembles of 50-day primitive-equation ocean model simulations with realistic topography, simplified lateral boundary conditions, and forcing from both idealized and observed wind time-series representative of the summer upwelling season, large ensemble and single-simulation variances were found downstream of major topographic features on the shelf. The simulated predictability experiments, in which model forecasts were verified by standard statistics including anomaly correlation coefficient and root mean squared error, suggested that, even under conditions of relatively weak wind forcing, the deterministic response is stronger than error growth due to instabilities or other effects over the 3-7 day forecast intervals considered. It follows from these results that important elements of the coastal circulation should be accessible to predictive, dynamical forecasts on the nominal 7-day predictability timescale of atmospheric forcing. A new variant of relative entropy, the forecast relative entropy, was introduced to quantify the predictive information content in the forecast ensemble, relative to the initial ensemble. More details on these simulations and results are provided by Kim et al. (2008).

Results from winter season simulations show evidence of systematic offshore Rossby-wave propagation of large-scale eddy features, similar to that observed by satellite altimetry. The response of coastal sea levels and depth-averaged alongshore velocity on the shelf to periods of northerly and southerly winds are accurately hindcast by the nested wintertime model. Careful attention to precipitation and river inflows is necessary to approximate observed salinity signals. During periods of downwelling, fresh water input by rivers is trapped close to shore. In accord with two-dimensional experiments, enhanced vertical mixing inshore of the downwelling front homogenizes the water column to as much as 50 m depth. At the first episode of locally upwelling-favorable winds in mid-winter, the buoyant waters of the inner shelf spread seaward where they are rapidly mixed away. By late winter, the decreasing occurrence of downwelling relative to upwelling prevents the recurrence of pervasive freshwater on the inner shelf.

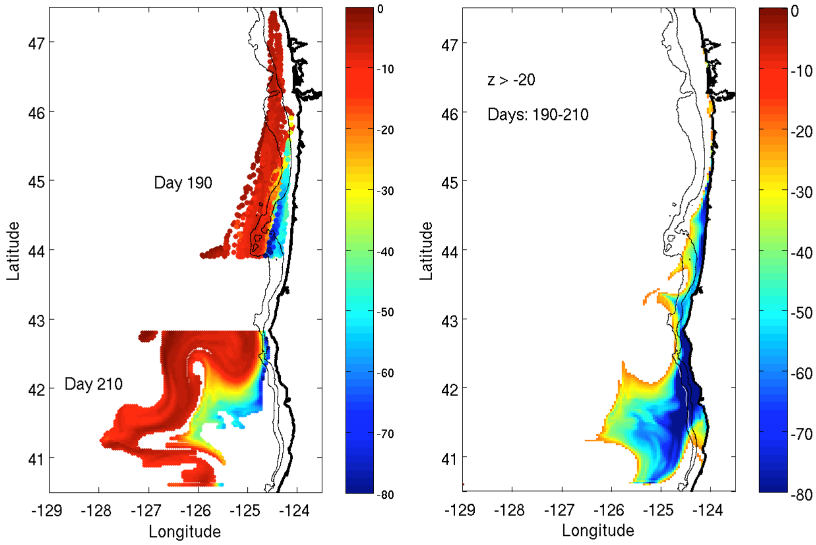

Figure 1: (left panel) Lagrangian label tracer location on 9 July 2001 (day 190, north of 44º N) and the same patch of tracer at the surface on 29 July 2001 (day 210, south of 42.8º N), from the nested OCTZ simulations. At both times color corresponds to the depth of the tracer on 9 July. (right panel) All Lagrangian labels that were deeper than 20 m on 9 July (day 190) but are at the surface on 29 July (day 210). The additional upwelled water in the south is due to upwelling that occurred south of Cape Blanco (42.8º N) rather than around Heceta Bank (44.2º N).

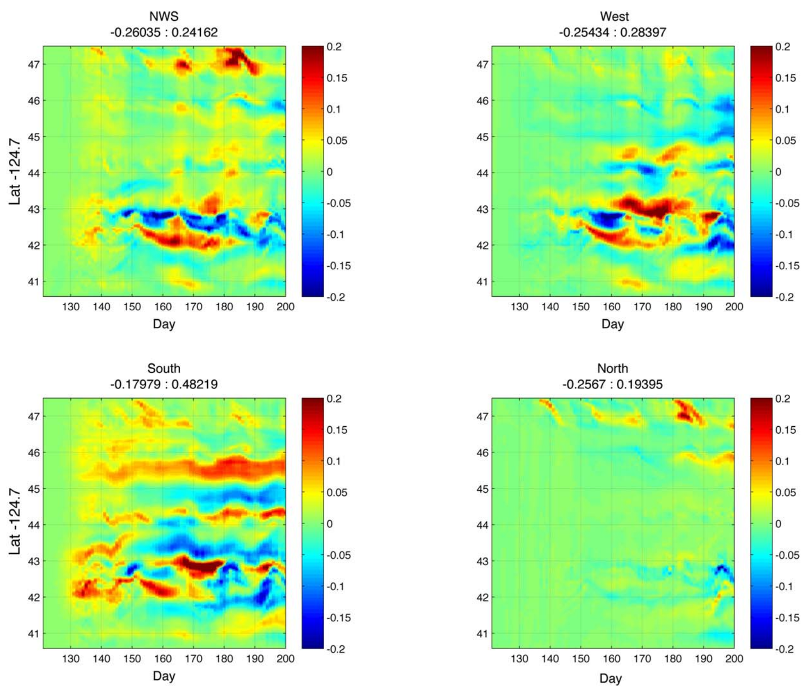

Figure 2: Hovmüller diagrams of depth-averaged meridional velocity at longitude 124.7 ºW (see Figure 1 for domain geometry) vs. time (days) and latitude (ºN), for perturbations at (upper left panel; NWS) all open boundaries, (upper right; West) the offshore boundaries only, (lower left; South) the southern near-coastal boundary only, and (lower right; North) the northern near-coastal boundary only. Boundary perturbations were increased linearly from zero during Days 120 through 130, and then held at a steady value for Days 130 through 200.

Ensemble simulations with imposed boundary perturbations illustrate the different mechanisms by which information supplied at the different boundaries propagates into the domain and influences the interior solution, and their relative efficiencies (Figure 2). Disturbances at the southern boundary propagate rapidly northward along the coast as coastal trapped waves, affecting the circulation over the shelf, and, on longer timescales, over the slope and farther offshore, where separated and jets and eddies penetrate the interior. Disturbances at the offshore (western) boundary initially have little effect on the circulation, influencing the flow primarily after Day 150, by which time they have propagated slowly counter-clockwise around the artificial boundary to the southern boundary, due to necessarily imperfect open boundary conditions, and from there northward along the coastal boundary, in a manner similar to the southern boundary disturbances. Disturbances at the northern boundary are advected southward along the slope by the upwelling jet, an intrinsically nonlinear, state-dependent process, and have only limited effect on the shelf circulation, and almost no effect on the interior, through Day 200 of the simulation period.

RELATED PROJECTS

The model results obtained in the project are being compared with in-situ measurements from the National Science Foundation Coastal Ocean Processes/Coastal Ocean Advances in Shelf Transport (CoOP/COAST; http://damp.coas.oregonstate.edu/coast/) and Global Ocean Ecosystem Dynamics/Northeast Pacific (GLOBEC/NEP; http://globec.coas.oregonstate.edu/) field experiments. The research in this NOPP project is being closely coordinated with work in the OSU component of the GLOBEC/NEP project 'US-GLOBEC/NEP Phase IIIa – CCS: Effects of Meso- and Basin-Scale Variability on Zooplankton Populations in the CCS Using Data-Assimilative, Physical/Ecosystem Models' and in the OSU ONR project 'Data Assimilation in Shelf Circulation Models.'

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